PREDICTING THE LIFE OF SKIRT SUPPORTS IN PRESSURIZED REACTORS UNDER CYCLIC CONDITIONS

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ABSTRACT

A common problem with skirt support is the occurrence of cracks originating at the outer boundaries of the welded junction. In order to understand the background on this, a study of the changes in temperatures and stress profiles has been undertaken by placing strain gages and thermocouples near the attachment region of an existing delayed coking reactor. Stresses arising from the differential thermal expansion, junction momentum and other contributions have been examined in terms of the Weil-Murphy analysis of the problem to provide a basis for validating models of stress failure.

INTRODUCTION

Mechanical designs of reactors are usually based on steady-state operating conditions and ignore stresses which arise during process transients, such as in emergencies or at start-up and shut-down. For continuous processes this is not a major problem because transients occur only infrequently. In the case of batch operations, however, transients are a normal part of the production cycle and so the effect need to be examined in more detail.

In particular, welded skirt supports of the type commonly used in vertical pressurized reactors are often subject to fatigue failure. The cycling causes abnormal transient thermal stresses in the vessel near these joints which tend to progressively weaken the structure. It is therefore important to look into ways in which this deterioration in the structural integrity can be mitigated by looking at the effect of transient changes occurring during batch operations particularly in terms of how the frequency and magnitude of the changes can be accommodated to ensure safer designs and how this might have to be reflected in operating policies which will maximize equipment life.

DIFFERENTIAL STRESS ANALYSIS

The main stress components at the skirt junction can be calculated using beam on elastic foundation theory (1) applied to a three-cylinder junction, as suggested by Weil and Murphy (2).

To assess fatigue, the stresses of major concern are those arising in the outer skirt region, since the weld is much more susceptible to this kind of failure than the vessel plates as has been verified in studies of the origins of cracks occurring in operational units. All the evidence suggests that the outer surface of the attachment weld is the starting point.

During the normal operation of the drums, heat flows from the hot vessel walls to the skirt attachment. When the reactor is cooled, the flux is in the opposite direction. The calculation of thermal stresses (which are the major components) requires thermal gradients to be estimated in the skirt, shell and conic sections. The largest gradients occur near the junction because the flow of heat to or from the skirt is by conduction through, although radiation and convection between the conic and skirt sections are important if there is no insulation. Heat accumulates as a result of the axial heat flow and causes the magnitude of the gradients to decrease away from the region.

In this study, thermocouples were placed close to the weld at the skirt, shell and conic sections and are spaced at short intervals (Figure 1). At low heat flux, the temperature differences between neighboring points are similar but because the gradients are estimated by finite difference approximation, the numerical estimate is subject to noise (Figure 2). Mean gradients for the shell, skirt and conic sections can be calculated using the temperature readings over wider intervals. It can be seen that this represents the average behavior fairly well (Figure 2) and effectively filters out the noise. Consistency in the results can be verified by comparing these values with those estimated for adjacent thermocouples then computing an average gradient (for example, calculating the average gradient at the shell both with (NE1-NE5)/4 and (NE2-NE5)/3.

RESULTS AND DISCUSSION

During the cooling operation, the reactor full of coke is quenched with water. Figures 3-6 present the temperature change at four angular positions. Before switching the reactor (10.47 h), heat flows axially from the shell to the skirt and cone (Figures 7-10). This is consistent with the assumption of a main flow channel located centrally inside the vessel. The furnace effluents flow up through this channel to the top of the coke bed where the hot liquid accumulates. The coke deposited around the walls of the shell and conic sections acts as an insulating layer, limiting heat flow to the axial direction. As the drum fills up, the highest wall temperatures gradually move upwards. The lower part of the wall gradually cools down because heat is lost through the external insulation, but the temperatures are maintained at somewhat lower levels by axial and radial heat transfer. The temperature at the inlet nozzle is 490 C with the wall temperatures gradually falling from 390-435 C (a few hours after the drum starts to fill) to 300-325 C (before the next switch).

The temperatures in the lower left quadrant before the switch are somewhat higher than in the other positions, which are fairly uniform (Figures 3-6). This suggests that the main channel is located off-center and close to this quadrant. However, during cooling, the upper right quadrant cools faster. Had the channel being located closer to the lower left, it would have cooled faster, since quench water could be expected to spread radially from the central channel towards the walls. The most difficult zone to cool is the first quadrant, only being active after 9.6 hours. This means that this region behaves as if no cooling has taken place.

In Figures 3-6 it can also be seen that the switch and the steam stripping stages (both the 'small', 5 t/h, initiated immediately after the switch and the 'large', 15 t/h, initiated at ~ 11.85 h) do not seem to contribute to cooling of the reactor walls, since the temperatures remain unchanged during these operations. The heat transfer between the steam and the coke is poor, since convective heat transfer coefficients are known to be much smaller than boiling coefficients. It is also difficult for the steam to flow through the parts of the coke bed closer to the vessel walls. Strictly, an enthalpy balance on the steam during the stripping cycle is necessary to clarify this point but the top temperature is not accessible. The temperature of the gasoil quench remains constant during steaming, which suggests that only the central portions of the coke bed are exchanging heat.

It should also be noted that the production of lighter fractions due to thermal cracking is still significant even a long time after the switch has been made. The steam mixes with the vapors resulting only in a small temperature drop at the top. This requires estimating the oily fractions recovered from the blowdown system in order to compare the relative flow rates of hydrocarbons and steam at the top.

Increasing the pressure in the drum during the stripping operation would be beneficial to make it possible to penetrate deeper into the coke bed and so reduce the partial pressure in the zones closer to the walls. This increases the removal of hydrocarbons and cools the coke bed.

The important features contained in Figures 3-6 relate to the differences in the local curves, not the trend suggested by the general rate of change in temperature reflected in the different quadrants. Thus, the local spatial gradients in NW do not change much with time and the average value of temperature changes little. On the other hand, there is a significant change in average local temperature in SW ~200 C but little change in the local temperature differences, so the local gradient remains more or less constant. In the case of NE and SE, the local gradients are larger during part of the transient because of increases in local temperature differences. It is clear that the rate of change of temperature with time is not therefore in itself an indicator of significant changes in temperature gradient and by implication the local stress.

The calculated stresses are all very small (Figure 11 shows the longitudinal stresses at the outer skirt as an example) and far from the yield limit (~ 210 MPa). This is to be expected considering the modest thermal gradients observed. In the third quadrant the forces are slightly lower and decline faster than at other positions. On the other hand, in the first quadrant there is change from tension to compression at a certain point, which is important in fatigue assessment if fast quench rates results tend to exacerbate this. Generally, no residual forces seem to remain as the vessel is cooled down, apart from those due to the weight of coke and water.

As water evaporates, the pressure rises and if care is not taken, it can result in activation of the safety valve, causing a shut-down. A delay occurs in the response of the pressure to the water flow rate and the pressure sometimes rises, even after the water flow rate has been reduced, and requires careful attention to ensure it does not cause problems.

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One strategy used is to close the top valve a little in order to increase the pressure in the vessel. This practice has originated in a plant where the delayed coking units tend to be a production bottleneck. Experience has shown that restraining the top valves promotes radial flow of water through the coke bed, which accelerates cooling.

Successive runs show that parts which appear to be difficult to cool change randomly, indicating that the main channel is deviating from the center. Before the cooling stage, heat flows towards the junction at the shell and away from the junction at the skirt and conic sections. This is followed by heat flow in the opposite direction in the shell and skirt immediately after the cooling phase. The gradients in the conic section are initially positive then decrease soon after the start of the cooling cycle. Sometimes they are negative or increase again after a short drop.

The skirt and cone generally have more similar temperatures. The slower cooling rates and the gradients which develop in the conic section are caused by competition between the heat removed from the wall to the coke bed and heat supplied by the skirt attachment through the welded joint, as well as by radiation and convection. The form of the weld can also cause the heat which is retained in the skirt to move into the conic section which would explain why the shell cools faster than the conic section.

Figures 12-20 show that for rapid preheating (sometimes the cycle is delayed and requires heating the drum at a fast rate), variations of 1.6 C/min are obtained, which compare with the 1.6-1.8 C/min reported by Lieberman for a fast warm-up operation where one third of the vapors from the full drum are by-passed to the empty one (3). The high temperature gradients result in higher thermal stresses than those found in any of the cooling runs analyzed, but are still less than the yield limit.

CONCLUSIONS

The results indicate that the stresses that define the life of the skirt attachment weld on a fatigue basis are mainly established during warm-up or perhaps shortly after switching on. The inversion of stresses observed during the cooling operation at the outer region is mild and does not seem to be significant as far as fatigue assessment is concerned.

Switching to a cold drum should be avoided if at all possible. The results reported here suggest that this event could give rise to significant stresses in the coke drum, higher than for any other case and probably above the yield limit. To assemble useful information, it is necessary to have access to a suitable model since collection of experimental data on an extended experimental program is not feasible.

The results illustrate the importance of operational practices. Policies designed to increase the life of the skirt attachment weld should focus on warm-up and switch conditions or factors that could reduce the available time for warm-up (such as a delay in cutting the coke or an excessively slow cooling operation). Design should ensure sufficient drum capacity.

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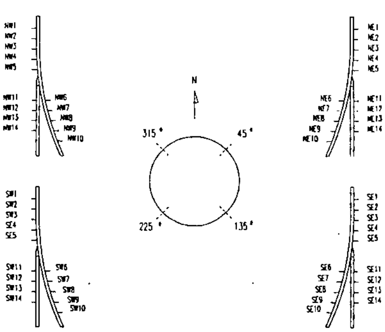

Figure 1 Location of thermocouples at the shell-skirt junction.

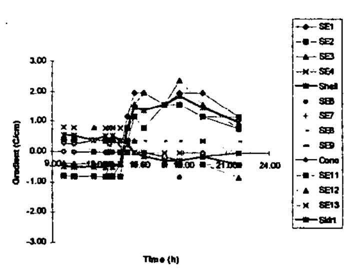

Figure 2 Typical axial temperature gradients. Positive values indicate heat flowing from the junction, dark lines represent average values.

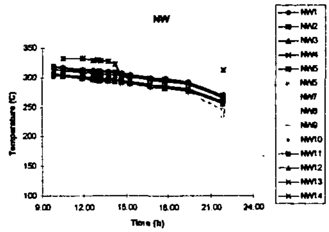

Figure 3 Skin temperatures at NW.

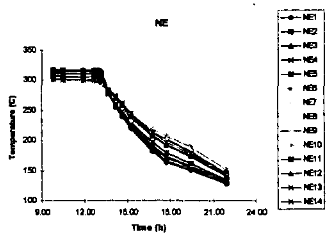

Figure 4 Skin temperatures at NE.

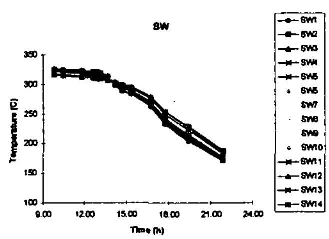

Figure 5 Skin temperatures at SW.

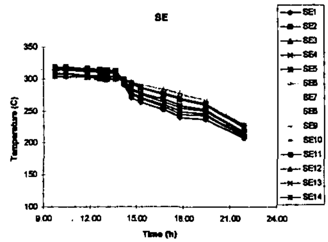

Figure 6 Skin temperatures at SE.

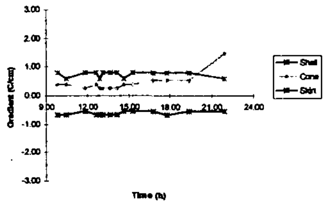

Figure 7 Axial gradients at NW.

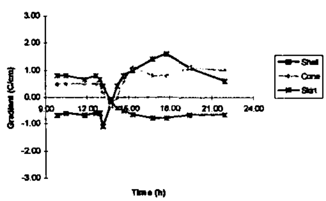

Figure 8 Axial gradients at NE.

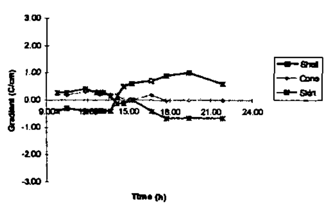

Figure 9 Axial gradients at SW.

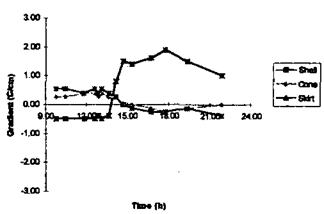

Figure 10 Axial gradients at SE.

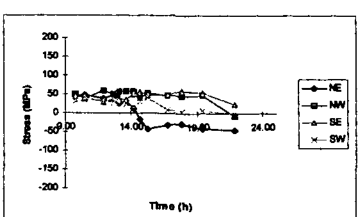

Figure 11 Longitudinal stresses at the (outer) skirt during cooling.

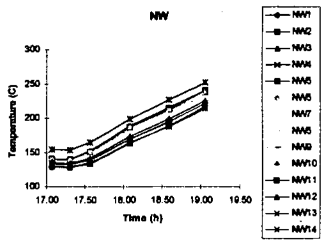

Figure 12 Temperatures at NW.

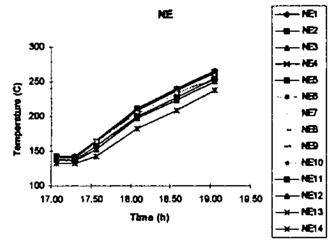

Figure 13 Temperatures at NE.

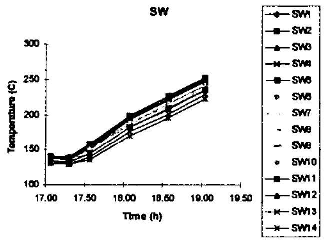

Figure 14 Temperatures at SW.

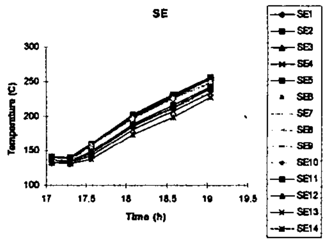

Figure 15 Temperatures at SE.

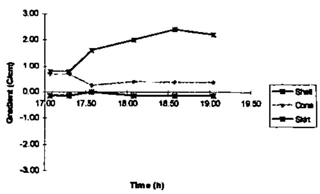

Figure 16 Axial gradients at NW.

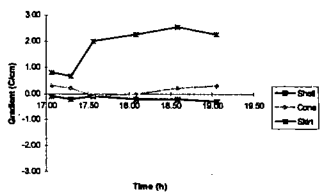

Figure 17 Axial gradients at NE.

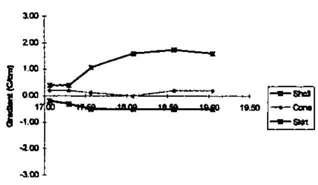

Figure 18 Axial gradients at SW.

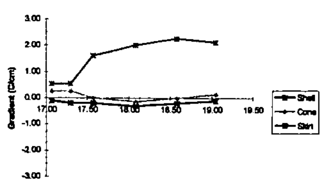

Figure 19 Axial gradients at SE.

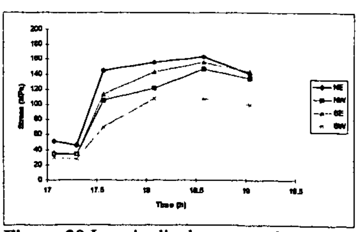

Figure 20 Longitudinal stress at the (outer) skirt during a fast pre-heating operation.